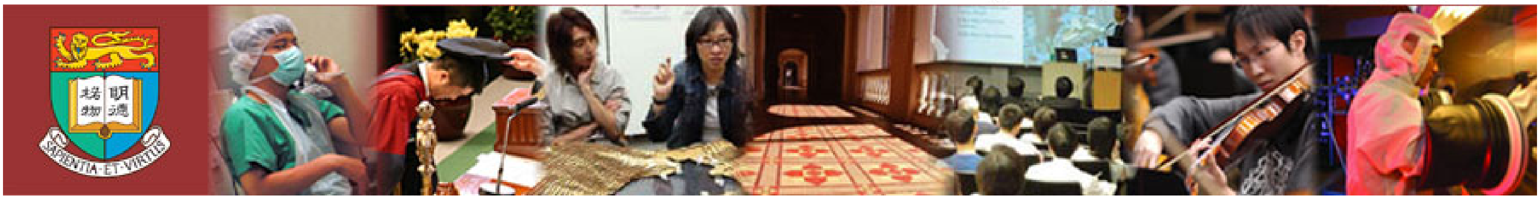

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Non-verbal inhibitory control of proactive interference

in a probe-recognition task

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Abstract

The present study investigated nonverbal inhibitory control of proactive interference in normal individuals using a probe-recognition task. Visual stimuli consisted of 130 abstract figures selected or modified from the Aggie Figure Learning Test (Majdan, Sziklas, & Jones-Gotman, 1996). The performance of 34 undergraduate participants showed a significant visual similarity interference effect, indicated by prolonged response times and reduced accuracy rates, only when the target probe was related to an item in the negative same list condition but not in the negative previous list condition. This implied that the effect of non-verbal proactive interference affected items that were relevant, in the same trial, and did not extend to items that were no longer relevant, in the following trial. The present findings suggest evidence for an inhibitory control process being carried out to prevent cross-trial visual similarity interference. Possible modifications to the negative same list condition for improving test validity are discussed.

Introduction

Executive function can be defined as a set of cognitive abilities that enable individuals to regulate, plan and organize behavior, language and reasoning in order to solve problems in daily lives and is generally believed to be supported mainly by the prefrontal cortex (Fuster, 2008). Two prefrontal functions: working memory and inhibition processes have been important domains in recent research. Although arguments exist in whether inhibition serves as a component of attention and working memory, it is generally agreed that the three are intimately related, and they interact to generate various behaviors (Friedman & Miyake, 2004; May, Hasher, & Kane, 1999; Miyake et al., 2000; Roberts, Hager, & Heron, 1994). Inhibition and interference control, despite its broad and inconsistent definitions across theorists (for reviews, see Friedman & Miyake, 2004), essentially emphasize the ability to suppress irrelevant information of all kinds in the current operation of working memory (Nigg, 2000). For example, in the classic Stroop Task (Stroop, 1935), the participant has to resist a dominant tendency to read out the colour word but instead concentrate on naming the colour of the words. Here the interference from the word has to be inhibited for the working memory to process only the colour.

Inhibition was once considered a component of the Supervisory Attention System (or later a controlled-attention capability within working memory) to maintain task-goal in active state and resolve interference (Kane, Bleckley, Coway & Engle, 2001; Shallice & Burgess, 1993). Later, Nigg (2000) established the conceptual distinctions among three kinds of inhibition-related functions--- prepotent response inhibition, resistance to distractor interference and resistance to proactive interference (PI). Such distinctions were further tested by Friedman and Miyake (2004). The first involves the ability to actively suppress dominant habitual responses as in the anti-saccade task (Hallett, 1978) and the Stroop task (Stroop, 1935); the second involves the ability to resist irrelevant information but focus on the task in hand; finally, PI involves the ability to resist memory intrusions coming from prior information which was previously relevant. In Friedman and Miyake's study, 220 adults were recruited to complete nine pre-existing well-established tasks, which were hypothetically grouped under the three functions. Results from latent-variable analysis implied that the three functions are separable, with resistance to PI being unrelated to the other two, having nearly zero correlation. For simplification, an umbrella term 'inhibitory control' would be used hereinafter, and be further specified when needed.

The development of inhibitory control theories have been influenced from research perspectives involving normal and disordered populations, such as attention-deficit/hyperactivity disorder (ADHD; Nigg, 2001), autism spectrum disorder (Ciesielski & Harris, 1997), psychological disorders, e.g. schizophrenia (Daskalakis et al., 2002), as well as individuals with age-related declines in cognitive abilities (Hasher & Zacks, 1988). Often deficient inhibitory control was proposed in an attempt to explain or describe pathological behaviors related to attention and memory functions.

From a broader perspective, studies involving interactions of components of inhibitory control and working memory have been growing. Along the direction of inhibitory control processes, its role in attention tasks without memory requirements was demonstrated in two types of interference conditions: prepotent response inhibition as in the Stroop and anti-saccade tasks (Roberts et al., 1994; Kane et al., 2001; Kane & Engle, 2003) and resistance to distractor interference as in the Erikson flanker task (Eriksen & Eriksen, 1974).

On the other hand, the role of inhibitory control in short term memory, namely resistance to proactive interference, has been investigated through serial recall (Martin & Lesch, 1996) and probe recognition tasks (Hamilton & Martin, 2007). These two lines of research seemed to distinguish between patients with deficient inhibition, inattention and in short-term memory (STM). Autism tends to belong to the former, while aging population

(Chiappe, Hasher, & Siegel, 2000) and patients with STM deficits due to brain lesions falls into the latter.

Along the direction of working memory components, a number of studies examined both verbal and non-verbal STM involving patients with neurological disorders. There was evidence for a double dissociation between verbal and non-verbal visual-spatial short term memory from patients with Down's syndrome and William's syndrome (Wang & Bellugi, 1993; Jarrold, Baddeley, & Hewes, 1999). While patients with William syndrome had better performance in a verbal-short term memory task, those with Down's syndrome had better performance in visual-spatial short term memory task. Barca, Cappelli, Giulio, Staccioli, and Castelli (2010) also attempted to develop a comprehensive out-patient assessment protocol involving examination of the visual cognitive functions of children with cerebral palsy by a selection of various tasks.

Among the numerous investigations, Martin and Lesch (1996) reported a patient with semantic STM deficits, who was susceptible to intrusions of previously presented materials in a serial recall task. His performance supported the findings of Martin, Shelton, and Yaffee (1994) that patients with selective semantic STM deficits were less able to maintain lexical-semantic information in memory but were able to maintain phonological information better. Their performance pattern was distinguished from that of patients with phonological STM deficits. The single-case study of Hamilton and Martin (2005) further revealed a dissociation between verbal and nonverbal inhibition based on a statistically significant difference in performance between a verbal probe-recognition task and a nonverbal anti-saccade task. The verbal probe recognition task requires the subject to determine whether the target word has appeared in the list immediately shown before. The anti-saccade task requires the subject to actively resist a reflexive saccade and detect the briefly presented target on the opposite side of the screen. Supported by the aforementioned 'controlled attention' account from Roberts et al. (1994) and the correlational findings of Kane et al. (2001) that anti-saccade task performance, which involves controlled attention, is highly correlated with working memory performance, this comparison would seem reasonable. Both the probe-recognition task and anti-saccade task have also been proven sensitive to inhibition deficits and regarded as potential tools for diagnosing ADHD and dyslexia (Everling & Fisher, 1998). Nevertheless, with recent research efforts in defining inhibition from different dimensions (Harhnishfeger, 1995; Nigg, 2000) and deconstructing it into various separable components (Friedman & Miyake, 2004), it may not be a sound contrast to compare performance in probe recognition and anti-saccade for demonstrating a dissociation between verbal and nonverbal inhibitory control, because the two tasks require different underlying mechanisms of inhibitory control.

The anti-saccade task involves intentional behavioral inhibition for habitual response: saccades, acting as competing stimuli. On the other hand, the probe recognition task involves cognitive inhibitory control over proactive interference due to unintentional intrusion of previous list items stored in short-term memory. This is consistent with the interpretation of Miyake et al. (2000) of prefrontal processes which includes shifting, updating and inhibiting, implying that the two tasks load on different processes. The anti-saccade task loads on inhibition whereas the probe-recognition task loads on both updating and inhibiting. In other words, there is memory requirement in the probe-recognition task but not in the other.

Considering the patient with semantic STM deficits reported in Hamilton and Martin (2005), the verbal probe-recognition task he performed required him to mentally recall list items within each trial in STM. His failure to inhibit memory traces of recently presented stimuli that became no longer relevant would indicate difficulty with resisting proactive interference. His normal performance in the anti-saccade task might reflect normal resistance to reflexive saccade, a kind of prepotent response by controlled attention, but the observation said little about the integrity of the resistance to proactive interference. Comparisons using verbal probe-recognition task and the anti-saccade task did not properly reflect a complete picture of his nonverbal inhibitory control, in the domain of proactive interference. A valid comparison to investigate the dissociation between verbal and nonverbal inhibitory control would require the involvement of the same inhibition processes, contrasting only the modality of input stimuli. There is a need for a non-verbal version of probe recognition task to be developed, which serves as the most suitable correspondence for reflecting non-verbal inhibitory control for proactive interference. Only when patients' data in both the verbal and non-verbal probe-recognition tasks were compared could the claim regarding any dissociation exist between the two modalities of inhibition to be verified.

The current study

In the present study, a nonverbal probe recognition task was developed based on the verbal recent-negatives task of STM used by Hamilton and Martin (2005; 2007). The task would use non-verbal stimuli in the form of two-dimensional, black and white line-drawings selected and modified from figures in the Aggie Figure Learning Test (Majdan, Sziklas, & Jones-Gotman, 1996), a visual-perceptual test for evaluating memory functions in English and French speaking populations. Therefore, the task could serve as the non-verbal analogue of the modified recent negatives verbal probe recognition task. It was designed to elicit proactive interference on nonverbal input, and hence investigate the patterns of inhibitory control. The task should be able to rectify the limitations of using the anti-saccade task to study non-verbal inhibitory as a comparison of the verbal probe recognition task to illustrate non-verbal and verbal dissociation (Hamilton & Martin, 2005).

The current task is a modified version of the one developed from a pilot study of Law (2008), in which the data obtained failed to demonstrate the effect of inhibiting proactive interference or reflect basic memory functions. That version of the task involved three list items and a probe in each trial. The overall accuracy for some of the conditions in most participants was not above chance level. The performance was hypothesized to be related to task difficulty as high memory demand of visual information was required for each trial. The current task reduced the number of list items by one in each trial. It is hoped that this modification would be within visual-spatial STM capacity of participants and could adequately elicit the working of inhibitory control over specific conditions.

This study aimed to contribute to the current literature on inhibitory control by establishing a non-verbal task for PI. The outcome would be valuable for investigating the role of non-verbal visual representations in eliciting interference. When tasks tapping attention and STM inhibitory control separately are available, components of working memory functions could be further differentiated. A task focusing specifically on the visual-spatial working memory would help to pave the way for future studies for understanding verbal and visual-spatial inhibitory control abilities of individuals with various dimensions of cognitive deficits, such as patients with focal and diffuse brain lesions, progressive diseases such as dementia, neurodevelopmental syndromes like Down's Syndrome and William's Syndrome, mental retardation as well as cerebral palsy. Normative performance from Chinese participants can serve as a standard for comparison. With the advancement in neuroimaging techniques, it may stimulate further studies of the locus of cerebral cortical areas and pathways responsible for verbal and non-verbal inhibitory control.

Method

Participants

Forty-eight undergraduate students at the University of Hong Kong participated. There were 24 females and 24 males, all within the 19-24 years age range. Average age was 20.8 years. They were native speakers of Cantonese with reported normal or corrected to normal vision.

Materials

Test items consist of 130 abstract figures in total. Most of them were selected from the Aggie Figure Learning Test (Majdan et al., 1996) and the remaining were modified versions of the selected ones to create visually similar items. All figures are black and white line-drawings that cannot be associated with a label or a description in conventional linguistic code. To reveal visually similar interference effect, each trial in the negative same list condition contained a stimuli and probe target which were matched as a pair. Each pair shared similar outline and configurations but, differed along one of two dimensions: spatial orientation (mirror images and rotation) and/or minor details (addition, deletion, distortion of parts). There were 12 trials for pairs differing along each dimension. *Figure 1* shows examples of five types of similar pairs.

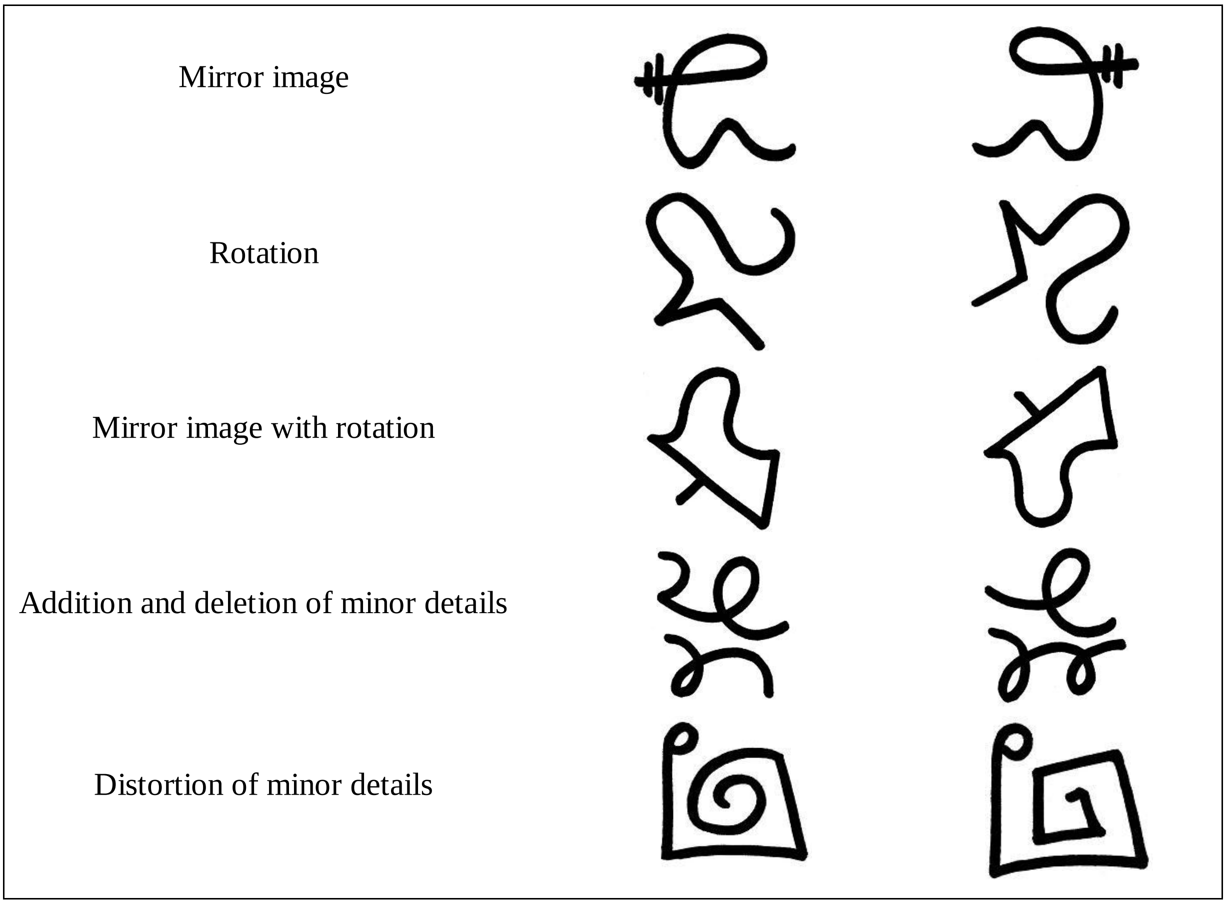

Figure 1. Example of visually similar pairs

List conditions

Four experimental conditions based on the memory probe paradigm developed by Monsell (1978) and further specified in the second experiment of Hamilton and Martin (2007) were constructed. In each trial, the participant was presented a list of two items, followed by a probe figure. He had to respond *yes* or *no* according to whether the probe had appeared in the list. The target probe could occur under one of the four conditions, in which one condition for positive response and three for negative. The positive condition is one in which the target being exactly the same as one of the two list items in that trial. The first negative condition, the unrelated condition, refers to the target being visually dissimilar to the list items in current trial or previous trial, yielding a clearly *no* response. The second, the previous list negative condition, refers to the target probe being visually similar to a list item in the immediately previous trial, and would likely elicit proactive interference and thus the work of inhibitory control. The third negative condition: the visually interfering same list condition contains trials in which the target is visually similar to one list item in the current trial, and is expected to elicit a large degree of visual interference. The previous list condition corresponds to the semantically or phonologically related conditions of experiment two in Hamilton and Martin's study on PI in verbal STM. It is used in this experiment to reveal an effective inhibitory control for irrelevant information in the previous list in individuals with normal resistance to PI interference. The principal effect of interest would be the contrast in response time and accuracy rates between the three negative conditions, specifically that the influence of proactive interference in the previous list or visual interference in the same list items could possibly reduce the accuracy. While an effective inhibitory control mechanism can resist the interference and resolve conflicts, it is hypothesized to prolong the response time.

Figure 2 shows an example of four consecutive trials from left to right to demonstrate the four experimental conditions. It is shown that the target probe in negative previous list condition being similar to the list item in the previous trial negative. Also, the positive matching stimuli for target probe may occur in list item position of 1 or 2. To balance the total number of positive and negative responses, there were 96 trials in positive condition, 24 in negative previous list condition, 24 in negative same list condition and 48 in negative unrelated condition. A total of 192 trials consisting of the four experimental conditions in fixed sequence were divided into six blocks and separated into two parts of three. Within each part the three blocks were randomized during task administration. Within the 32 trials in each block, the sequence of trials was fixed to eliciting proactive interference for the previous list negative condition. The participants' performance in the unrelated negative condition would serve as a baseline for comparison with the other conditions.

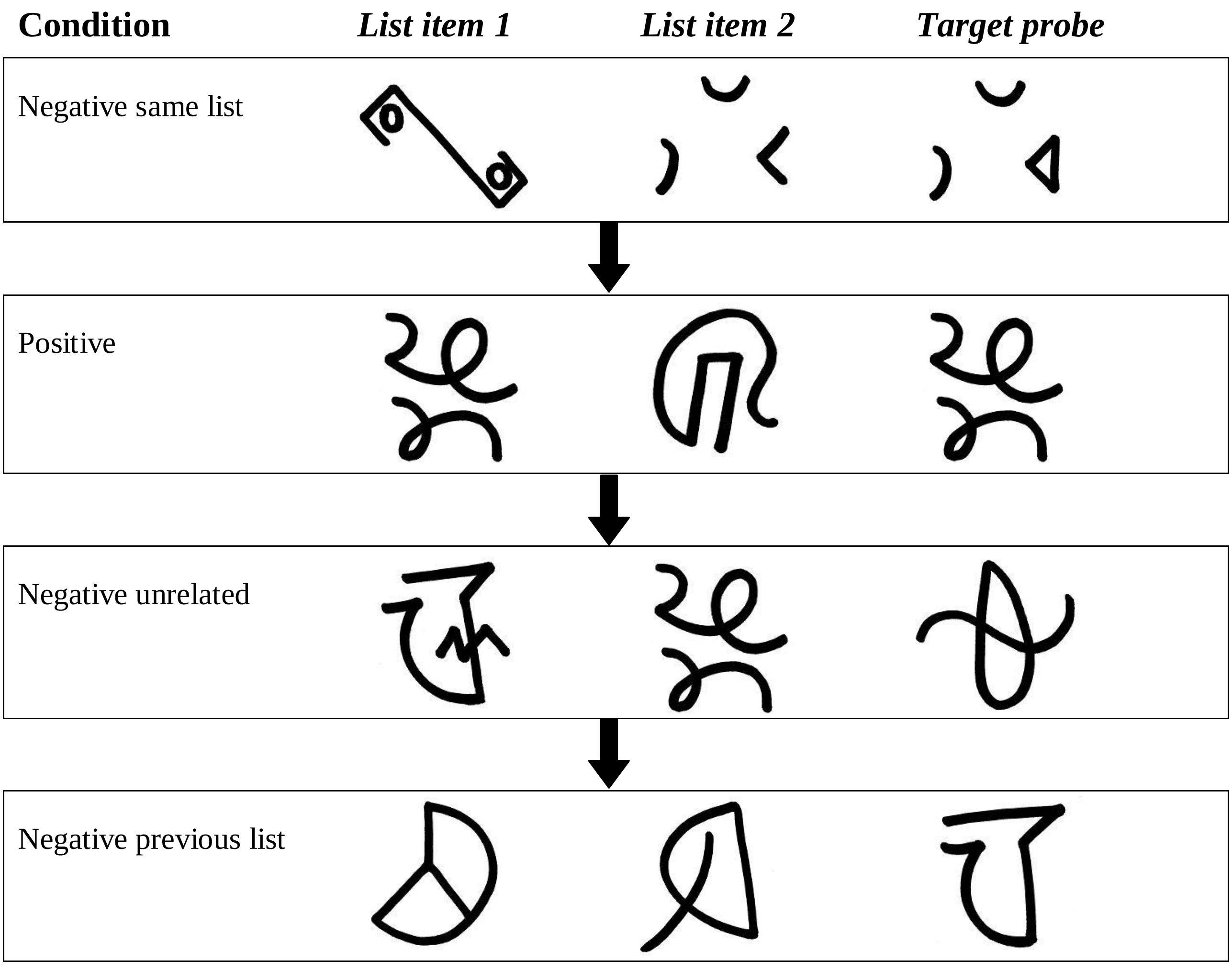

Figure 2. An example of four consecutive trials to exhibit four experimental conditions.

Design

The design contained one independent variable with the interference conditions being a within-subjects factor of four levels. The dependent variables were the recorded response latencies and the percentage of accuracy.

Equipments

The probe-recognition task was programmed using E-Prime Professional Software. The non-verbal stimuli were presented on a Fujisu brand laptop computer connected to an E-prime Serial Response Box for recording key-press response latencies and accuracy data.

Procedures

The participants were tested individually in a sound booth. They were seated in a stationary chair, at a comfortable viewing distance from the computer screen. Before the experiment began, they were told that the task was to judge whether they saw the same figure before in each trial. Then they were familiarized with the task by eight practice trials including the four conditions. They were given a feedback of correct or incorrect judgment after every practice trial. After that the experimental trials began.

In each trial, the participant was presented with two abstract figures serially on a computer screen, each for 750 msec and followed by 100 msec inter-stimulus interval. After the second figure, a row of **** will appear for 1000 msec to indicate the end of the list. Then the probe figure would appear for 750 msec. The probe figure would be immediately followed by a blank screen, which remained until the participant responded. The participant had to determine if the probe figure had appeared in the list by pressing the left key for 'Yes' and the right key for 'No' as soon as the probe was shown. After the participant made a response, the fixation points XXXX appeared for 1000 ms, followed by stimuli of the next trials. The six-block task was carried out within a 30-min session which was separated into two parts of three blocks each. The client could have a break after completing one part, and the second part began with the same eight practice trials as in the first part. Equal number of participants was assigned to start with either part one or two.

Data and Statistical analysis

Accuracy and response time on each trial were recorded. The average accuracy of each participant in any condition was arbitrarily set at 70% or above to ensure validity of the observations. Hence, subjects with accuracy rates lower than the criterion in any of the conditions were excluded for data analysis. In addition, trials with incorrect responses and those with correct responses but taking exceedingly long or unusually short RTs ($\pm$ 3 SDs) were removed. This applied to RTs for each participant by condition in the by-subject analysis, and by experimental conditions in the by-item analysis.

The effect of proactive interference was investigated by contrasting the accuracy and response time for each of the two "visually similar" conditions with the unrelated negative baseline condition. Descriptive statistics of mean and standard deviations for accuracy and reaction time were used to formulate a norm for normal adult subjects. The main effect of interference conditions on response latency and percentage error were evaluated by using one-way repeated measures ANOVA by subject as well as one-way ANOVA by item. Post hoc pair-wise comparisons for the two measures in each condition were carried out.

Results

The data of those participants with average accuracy less than 70% in any condition were discarded. As a result, 14 out of 48 participants in total were removed from data analysis, including seven males and seven females. They all had accuracy rates below 70% in the negative same list condition, accounting for 29% of the data.

Data of the remaining 34 participants, comprising of 17 females and 17 males were then analyzed. Response times (RT) from incorrect trials, or those deviated by more than three standard deviations from the participant's mean within each condition in the by participant analysis and from the mean in each experimental condition in the by item analysis were discarded. The above three criteria accounted for 9.96%, 1.50% and 1.16% of the data respectively. Analyses of the descriptive and inferential statistics were performed on the remaining data. Differences in response time and accuracy were examined through the one-way ANOVA test.

The means and standard deviations of response time and accuracy in each condition are presented in Table 1. In general, participants had the longest response latency in the negative same list condition and the shortest mean RT in the positive condition. Participants had the lowest accuracy rate in the negative same list condition. Accuracies in ascending order were the positive condition, the negative previous list condition and the unrelated negative condition.

Table 1

Means and standard deviations of response time and accuracy in different conditions

	Response time		Accuracy rate	
Conditions	Mean (ms)	SDs	*Mean (%)*	*SDs*
Positive	613.62	79.71	88.05	7.77
Negative Previous list	629.56	98.55	94.98	5.20
Negative same list	763.46	147.79	76.35	6.22
Unrelated negative	618.23	101.18	98.16	2.39

A one-way repeated measure ANOVA (*F1*) was conducted with the type of interference conditions as a within-subjects factor. The by item analysis (*F2*) using one-way ANOVA was performed with the conditions as within-items factor.

In terms of response time, there was a significant main effect of interference conditions on response time in both the by participant analysis and by item analysis, $F1$ (1.71, 56.41) = 41.72, $p < .001$ with the Greenhouse-Geisser correction, $F2$ (3, 65.917) = 30.11, $p < .001$ with the Brown-Forsythe *F*-ratio as the assumption of homogeneity of variance violated.

Post hoc pair-wise comparisons were conducted to compare the control condition, i.e. unrelated negative, with the other conditions. Bonferroni adjustment was used in the by participant analysis, and the Games-Howell procedure was used in the by item analyses as it does not rely on assumption of equal variance. Both by participant and by item analyses revealed that the average response latency in the negative same list condition was significantly longer than that in unrelated negative, negative previous list, and positive conditions with *p's* <.001. This indicates the presence of visual similarity interference in the negative same list condition. Under the experimental hypothesis that visual similarity interference was elicited in both the negative same list condition and in previous list condition, the results demonstrated an impact of the interference on response latencies in the negative same list condition, and suggested the presence of resistance to proactive interference in the negative previous list condition.

In terms of accuracy, participants had the lowest accuracy rate in the negative same list condition as shown in Table 1. Accuracies in ascending order were the positive condition, the negative previous list condition and the unrelated negative condition.

The repeated measure ANOVA (*F1*) was conducted per participant with the type of interference conditions as a within-subjects factor. Item analysis (*F2*) using one-way ANOVA was performed with the conditions as within-items factor. In terms of accuracy, there was a significant effect of interference on the accuracy rate in both the by participant analysis and the by item analysis, *F1* (2.11, 69.64) = 103.71, *p* < .001 with the Greenhouse-Geisser correction, *F2* (3, 35.833) = 23.43, *p* < .001 with the Brown-Forsythe *F*-ratio.

Post hoc pair-wise comparisons were conducted using the same adjustment methods as in the RT analyses. The results from both participant and item analyses revealed that the average accuracy rate in the negative same list condition was significantly lower than that in the negative unrelated condition with *p's* < .001. There were three additional significant pair-wise differences of the accuracy rates, including that between negative same list condition and positive condition, between positive condition and negative previous list condition and between negative previous list condition and negative unrelated condition, with all *p's* < .001. Yet, these three pairs of differences were not significant by Games-Howell test in item analysis.

To summarize, there were significant main effects of types of interference conditions for response time (RT) and accuracy rates in both participant and item analyses. Post-hoc analyses by participant and by item showed no significant differences for RTs between negative previous list and negative unrelated conditions, but a significantly longer RT and lower accuracy rate in negative same list condition than negative unrelated condition. There were significant differences in accuracy rates between the positive, negative previous list and negative unrelated condition in participant analyses but not in item analyses.

Discussion

The present study investigated the mechanism of inhibitory control on non-verbal proactive interference (PI) by contrasting the response time (RT) and accuracy rates in negative previous list condition with the neutral (negatively unrelated) and visually interfering (negative same list) conditions using a probe recognition task. The performance of undergraduate participants showed a significant non-verbal visual interference effect only when the probe was related to an item in the negative same list but not in the negative previous list condition, as the latter condition had similar performances to neutral condition. The presence of non-verbal visual interference in the negative same list condition provides insights into non-verbal domains in working memory, given most previous research focus on various verbal interference effects (Bartha et al., 1998; Hamilton & Martin, 2007).

Importantly, the effect of interference on response time affected items that were relevant (i.e. in the same trials) and did not extend to items in the following trial. This could aptly be explained by an inhibitory control process (May, et al. 1999) which removed no longer relevant items from working memory, and the reset mechanism (Miller, Li, & Desimone, 1993) between trials that prevent cross-trial interference. This means that the proactive visual interference due to stimuli in previous trial were inhibited and not carried over to the current trial. Only in the current trials, list items were actively retained in memory till the appearance of the probe. Prompt judgment of an identical match of the probe was greatly interfered by similar items in the list within the trial, leading to prolonged RTs and reduced accuracy rates in the negative same list condition.

The difference of effect of interference between the negative same list and negative previous list conditions is consistent with the findings of Hamilton and Martin (2007) that involved verbal stimuli. In their study, the undergraduate participants had significantly longer RTs in the negative same list but not in the negative previous list condition, implying interference effect for semantically and phonologically related items. Consequently, the present data in the non-verbal domain are likely to support the verbal data of Hamilton and Martin in illustrating the mechanism of inhibitory control on proactive interference. It is likely to be a more suitable nonverbal counterpart than the anti-saccade task in the single-case study of Hamilton and Martin (2005) to investigate dissociation between verbal and non-verbal inhibitory processes for PI. Future case studies in patients using this task could be conducted to testify the dissociation hypothesis.

However, some may argue that the minimal effect of non-verbal PI in the negative previous list condition was due to rapid decay of information from the previous trial. Under the decay theory (for reviews, see Berman, 2009), previous, older information gradually fades in short term memory trace as time passes and newly presented information takes up the capacity. Since current list items should have more information retained than previous list items in the decay process, they interfere with the recognition of target probes to a larger extent than previous list items do. Indeed, the current data do not allow the possibility of a rapid decay process to be ruled out unequivocally. Some insights could be found in the verbal recent-negative and the verbal analogue of the current task. Experiments of Hamilton and Martin (2005; 2007) found out significantly longer RTs in a recent negative condition than non-recent negative condition in normal individuals. The former involved a list item in the immediately preceding list being identical to the target probe in current trial and the latter involved a probe that appeared in three trials before. It should be noted that PI due to identical items were greater than PI from semantically or phonologically similar items. The results of their study implied that participants' memory capacity was adequate to retain information from the previous list. It was more probable to be inhibitory control that suppresses PI, resulting in a prolonged RT. The researchers also reported a patient with STM deficits who had a span of two to three items but experienced great proactive interference in the verbal probe-recognition task containing three list items per trial (Hamilton & Martin, 2007). Moreover, his errors in a serial recall task involved replacing more recent items with previous list items (Martin & Lesch, 1996). This could not be explained by the memory decay account but the intrusion of previously introduced information.

All of the above demonstrate that rapid decay would be less likely than inhibitory control process to account for the reduction in PI. The findings in the verbal tasks might also imply what actually happened in the non-verbal task. Further implications for theories of executive function and working memory can be done by investigating normal individuals and those with non-verbal working memory deficits in the future. Comparing performances of different individuals in the non-verbal memory span task, serial recall task and probe recognition task could possibly depict the existence of decay or inhibition processes, and even reveal any interaction of the two.

Apart from revealing an effective inhibitory control over non-verbal PI, there are two unexpected results in the present study. The first is the high discard rate of participants, 29% (14/34), due to their low accuracy rates in the negative same list condition. The rejected participants scored 66.67% (16/24) or lower in this particular condition. The lowest had 33% (8/24) accuracy, which was at the below chance level. However, the drawback of high discard rate could not be remedied by lowering the passing criteria for subject inclusion due to the second notable finding which follows.

Despite the high discard rate, the average accuracy rate for participants in the negative same list condition was still significantly lower, having only 76.35% compared to above 85.00% in all other conditions. This means on average each participant only had 18 correct trials out of the 24 trials in total for data analysis. In fact, accuracy for each individual should be above 83.33%, i.e. 20 correct trials in order to score beyond the chance level performance, as calculated by chi-square test. Out of the 34 included participants, only eight of them scored equal to or higher than 83.33% accuracy. The remaining 26 had accuracy as low as 70.83% (17/ 24).

Some may concern about the reduced validity of using the data of the 34 participants in the negative same list condition as normative values, and therefore would suggest raising the passing criterion to 83.33% accuracy, which is the statistical above chance level. If this criterion were employed, data from 26 more participants would have to be rejected from the beginning of data analyses, totaling an 83.33% discard rate of the 48 participants recruited. This would seem unreasonable as the majority of participants could pass the criterion for all other conditions except the negative same list condition. Moreover, this would pose further difficulty in collecting an adequate sample size for normative data. This is the reason that the 70% passing criterion for all conditions was adopted in the current study. This level assumed significantly above chance level for the overall data comprising four conditions, and yet retained adequate data for comparison in each condition. Indeed, the currently included participants had above 80% overall accuracy averaging the four conditions. This provides substantial confidence in the overall validity of the current included data for illustrating non-verbal inhibitory control functions and proactive interference. The data of RTs in the positive, negative previous list and unrelated list could serve as normative values, and implications contrasting the four conditions could be of important research and clinical uses.

To this end, the question of why participants made such a frequent incorrect judgment for the "visually similar but not identical" pairs in the negative same list condition should be addressed. There are three possible situations that may result in an incorrect response. First, participants might fail to notice the subtle differences between the list item and target probe, hence treating the two visually similar pairs identical. Secondly, they might have noticed some differences in the target probe from the list item actively retained in visual memory. However, the level of certainty for the differences was not high enough to trigger an inhibitory control for overcoming the interference from visual similarity that created a positive response bias. Lastly, the uncertainty in the difference and visual similarity interference may draw participants to respond by simply guessing. No matter which situation contributed the most errors made by participants having low accuracy rate, all three factors unanimously lead to the discussion of whether those trials were too difficult and suggest a need to lower the task demand.

The development of the current probe-recognition task aimed to be applicable not only to normal individuals but also individuals with various cognitive deficits, and should be sensitive enough to reflect in detail the proper or improper functions of non-verbal working memory and inhibitory control. For clinical uses, it is again implied that the current level of difficulty in the negative same list condition, at which considerable normal individuals failed to reach high accuracy, would need to be lowered. In other words, there is a need to increase the proportion of normal individuals' accuracy in the task.

Compared with the version in the pilot study (Law, 2008), the design of the current task already tried to reduce the memory load of visual information in each trial by reducing the number of list items by one from three to two for all conditions. The current list length seemed appropriate in the three other conditions, giving high accuracy of trials and illustrating experimental expectations. Hence changes should be constrained to the negative same list conditions but not other conditions. The only variable that could be altered without affecting the other conditions would be the degree of visual similarity interference between stimuli items and target probes. Different from the recognition of verbal stimuli that could be characterized using orthographic, semantic or phonological information, recognition for non-verbal visual stimuli only depend on the visual spatial features in brief presentation. The features used in this experiment that could distinguish the probe with the stimuli include differences in spatial orientation (mirror images and rotation) and minor details. Visual similarity has been in the form of outline and general configuration. A qualitative analysis of the visually similar pairs (stimuli and probes) could suggest ways for modification.

Considering the 24 trials containing visually similar pairs, half differ in spatial orientation and the other half in minor details. By calculating the average accuracy rate of participants' recognition for each pair, it was found that 11 pairs had accuracy below 75%. In other words, in the trials of the 10 similar pairs, nine or more participants incorrectly treated them as identical. The lowest accuracy (26.47%, 9/34) goes to the pair shown in *Figure 3* with type A modification. Only nine participants responded correctly for it. Specifically, among the 11 pairs of low accuracy, eight of them differ in minor details. Conversely, out of the 13 pairs which accuracy was higher than 75%, nine of them differ in spatial orientation of mirror image or rotation.

These findings have two important indications for the visual stimuli. First, approximately 11 pairs of stimuli should be modified for the aim of increasing the degree of contrast by exaggerating the existing differences, e.g. rotating the image on top of mirroring, further changes of minor details. Second, participants in general seemed to have higher accuracy in recognizing differences in form of spatial orientation differences than that in minor details. This pattern is also found in error analysis of rejected subjects. Hence modifications should be emphasized on the pairs with differences in minor details. *Figure 3* shows some suggestions for modification in each type of similar pairs.

Indeed, there are no currently available objective measures or quantification for various degree and types of visual similarities. Hence changes in the stimuli used for improving research output could only be conducted with subjective judgment of the researcher, which in fact was how the current version of stimuli was generated. The proposed modifications might not promise a reduction in the degree of visual similarity interference across all participants because there had been little evidence on whether different individuals perceive various types of visual spatial representation the same way. Some pilot testing may be needed to verify the effect of the fine adjustments.

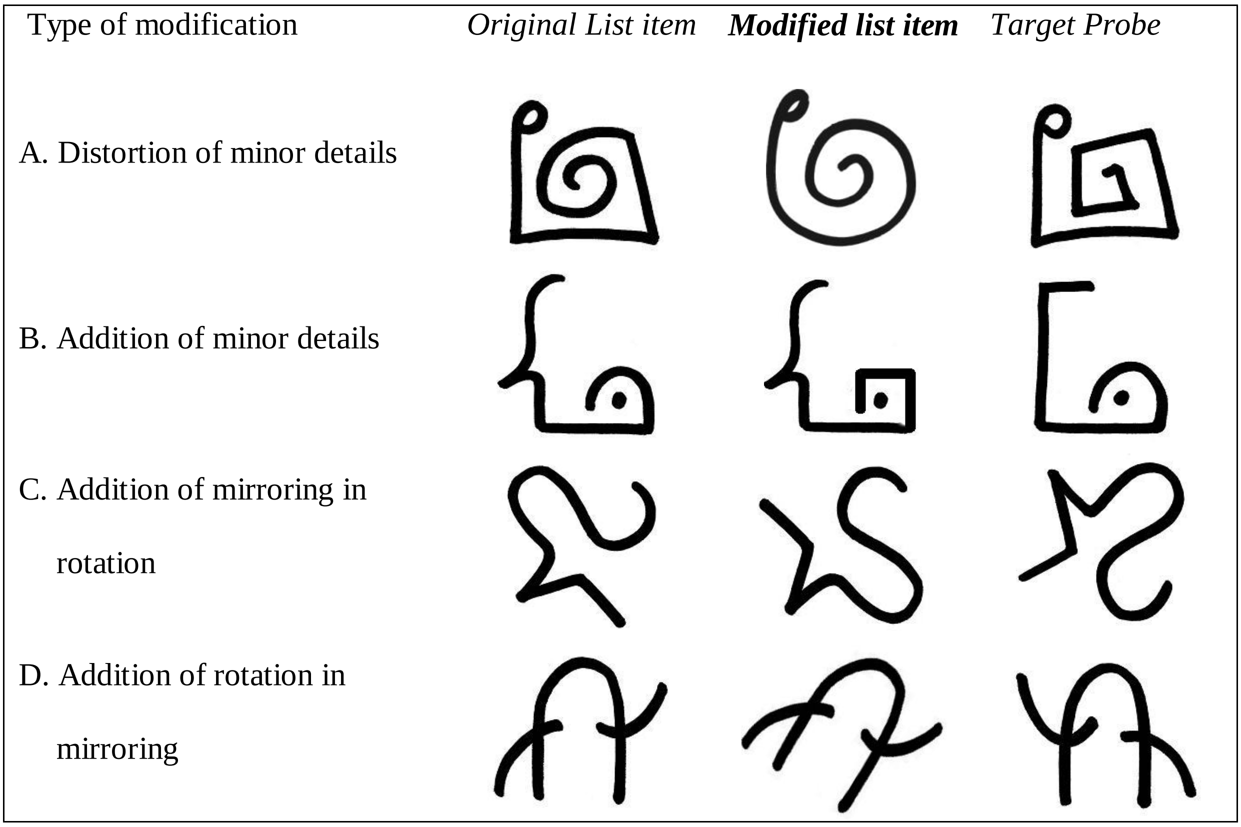

Figure 3. Suggestions for modification in pairs with low accuracy.

The error patterns of participants have also pointed to an interesting research direction. Could there be any differences in terms of processing non-verbal visual-spatial information between individuals with high and low accuracy? Further analysis found that the participants included for quantitative analysis previously and the discarded participants had similar error patterns in the negative same list condition: higher accuracy in recognizing changes in spatial orientation than minor details. This could indicate that high and low performers, as distinguished by the 70% criterion in this condition, had similar processing of the different types of visual representations in general. On the other hand, an interesting observation was found in the patterns of response times across the four conditions between the two groups. Although both high and low performers experienced significantly prolonged RTs, by more than 80msec, in negative same list trials and similar RTs between positive and baseline (negative unrelated) condition, low performers were observed to have RTs by 30msec longer in negative prelist condition than baseline condition, which highly indicated a proactive interference effect. Moreover, low performers were found to have over 20msec longer RTs in positive, negative same list and negative unrelated condition but a 30msec shorter RT in the negative same list condition. These observations lead to a search for the possible causes of the differences between the two groups.

Kane et al. (2001) tried to establish a link between attention and short-term memory capacity (measured in span) by comparing high and low verbal span individuals in the anti-saccade task, and found that high span individuals outperformed the low span ones in the task which required active attention control without a significant memory load. Conway, Cowan and Bunting (2001) also reported high-span individuals having a better resistance to distractor interference in a selective listening task. These studies might suggest that memory span size is related to accuracy in inhibitory control. In order to explore the possibility of span differences affecting inhibitory control functions, we hypothesize that accuracy in the current task is related to span size, and is more apparently illustrated in the negatively same list condition. Eight participants having accuracy in this condition beyond chance level (83.33%) were selected to represent the high span group. Eight rejected performers with lowest accuracy in the condition represented low span group. Their response latencies and accuracy rates were compared, and shown in table 2. The RTs of low performers in positive, negative previous list, negative unrelated list were 26msec, 60msec and 51msec longer than that of high performers (rounded off to the nearest msec.). Yet their accuracy rates in the three conditions were similar. Yet the average RT of low performers in negative same list condition was 50msec shorter than that of high performers. Although all the differences could not reach statistical significance, which could be due to other reasons such as low power i.e. few participants in each group, the trend could suggest that during normal situations, low performers could reach the same level of accuracy as high performers but they require longer processing time. In difficult situations as in the same list trials, their performance became affected seriously in a way that they may rely on guessing, hindering an effective inhibitory control process on PI to be carried out.

Table 2

Mean response time and accuracy of high and low performers in different conditions

	High performers		**Low performers**	
Conditions	Mean (ms)	Accuracy (%)	Mean (ms)	Accuracy (%)
Positive	626.49	86.20	652.46	87.37
Negative Previous list	611.90	95.83	671.46	94.27
Negative same list	770.01	84.89	720.17	52.60
Unrelated negative	610.59	98.70	661.94	95.83

Due to an inadequate number of high and low performers for comparison, further study of a larger scale would be needed to further replicate the observed differences between the hypothetical span groups, or to investigate the susceptibility to proactive interference in normal individuals with different performance levels. More proper measurements for memory span e.g. Corsi span (Milner, 1971) would be necessary. The present findings very much motivate the future research on how visual memory span measures are related to inhibitory control for PI and other inhibitory processes. From another perspective, the components of visual spatial memory representation and human’s susceptibility to different kinds of interference such as mirror image, rotation and minor details leave open an exciting research topic yet to be explored.

The current study has managed to establish a non-verbal task that shows promise of eliciting inhibitory control over proactive interference. Data in response times and accuracy rates help to testify the research hypothesis on inhibitory function and proactive interference.

Yet the low validity in one of the conditions might impede its generalization as population norms. Modifications are necessary for remediation of the current limitations. In the mean time, performance of participants in negative previous list condition and neutral condition could still serve as a reference for comparing nonverbal and verbal inhibitory control functioning in patients with cognitive impairment, in particular STM deficits.

Despite the current limitations, the present task is possible to be applied to neuroimaging studies e.g. fMRI study, for understanding functional localizations in the brain. The task may also serve as a tool for comparison with other neuropsychological tasks which tap various inhibitory functions, e.g. resistance to distractor interference and prepotent responses, to shed light on the investigation of the relationship among components of executive functions.

Beyond the theoretical level, the test may also be applicable to a variety of clinical populations. For instance, it may be used to investigate the inhibitory processes in the modality of visual-spatial short term memory in individuals with Down syndrome, who tend to have poorer verbal than visual spatial skills, and William syndrome, who tend to show the opposite pattern (Jarrold, Baddeley & Hewes, 1999). As the strengths and weaknesses in terms of modality are being identified, coping strategies or even facilitative means for communication may be devised.

Conclusion

The present study has demonstrated the effect of visual similarity interference on lengthening response time and lowering accuracy rate when the distractor is in the same trial but not across trials. This suggests evidence for a non-verbal inhibitory control function over proactive interference in normal individuals. Current data could serve as normative values for normal individuals while the findings also showed possibilities of different performance patterns in normal individuals. A variety of research directions have been generated. The development of theories in the field of inhibitory control, working memory and executive functions could be fostered. It is believed that further modifications in the negative same list condition on the task would be necessary to improve test validity, and hence increase its generalization to the normal populations as well as its functional significance of the test in clinical populations.

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